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Maintaining Aircraft Orientation Awareness with Audio Displays

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MAINTAINING AIRCRAFT ORIENTATION AWARENESS WITH AUDIO DISPLAYS

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This study was conducted to determine an appropriate task with which to test alternative orientation display formats, and to test a preliminary set of audio orientation symbology sets. Participants were required to perform three tasks simultaneously. The first task was a visual search (target designation) task. The second task was a radar monitoring task. Both of these tasks were performed on a head-down display. The third task consisted of monitoring aircraft orientation on a head-up display. The third task employed the study's one independent variable – orientation symbology sets. When performing the aircraft orientation task, orientation was displayed in three ways: visual only, visual plus discrete audio orientation information, and visual plus continuous audio orientation information. Performance measures on all three tasks were collected. Results showed that participants responded more quickly to changes in aircraft orientation with the presence of discrete audio orientation information. Lessons learned about the tasks chosen for this study and the audio display symbology sets are discussed.

Introduction

Pilots are required to perform many complex tasks during a mission. Obviously, one of the most important tasks is flying the aircraft, but when multiple tasks are cognitively and visually intensive, pilots can unintentionally lose track of the attitude of the aircraft. Primary flight information is continually presented on a visual display in the cockpit (and sometimes on multiple displays if both a head-down and head-up display are used), and pilots can also obtain visual orientation information from the out-the-window scene given good weather. However, pilots sometimes rely on (often erroneous) vestibular and proprioceptive cues to maintain orientation when performing other visually-intense tasks. When this happens, pilots can easily fall victim to spatial disorientation (SD) (Gillingham, 1992).

SD is defined as "failure to sense correctly the position, motion, or attitude of the aircraft or the pilot within the fixed coordinate system provided by the surface of the Earth and the gravitational vertical" (Previc and Ercoline, 2004, pp. 552). SD is most commonly described as two different types. Type I SD is called unrecognized SD and occurs when pilots are unaware that their perceived orientation is incorrect or different from their actual orientation. This often happens when aircraft undergo sub-threshold movements, causing pilots to perceive their attitude as straight and level when, in fact, they are banking. Type II SD is called recognized SD and occurs when pilots are aware that there is a mismatch between their perceived orientation and their actual orientation as displayed by the flight instruments or the real world. Statistics show that the majority of accidents attributed to SD are caused by Type I, or unrecognized SD. For example, a USAF study reviewing SD mishaps from 1989-1991 showed that 100% of these accidents were attributed to Type I SD (Lyons, Ercoline, Freeman, and Gillingham, 1994). Therefore, the primary goal of this research was to find ways to decrease the occurrence of unrecognized SD by helping pilots maintain orientation awareness throughout the entire mission. Currently, attitude information is primarily acquired visually. But as previously described, the visual channel often becomes overloaded and pilots' attention can become captured by a particular display or task (Foyle, McCann, Sanford, and Schwirzke, 1993; Weintraub and Ensing, 1992). The challenge is determining how one can prevent pilots from losing track of their orientation information when their visual channel is overloaded?

Because the majority of tasks in the cockpit rely on visual resources, audio displays are becoming more popular in the cockpit. Traditional audio displays are basic warnings used to alert pilots when a dangerous situation has arisen. However, audio displays are capable of providing additional information that might help resolve the Type I SD problem. Wickens'

Multiple Resource Model (1984) suggests that if one uses different resources to perform multiple tasks, the tasks can be performed more effectively than if all of the tasks required the same resources. Along those lines, using audio symbology to present attitude information was investigated in this study.

Objective

The objectives of this study were twofold. The first objective was to determine if the task chosen for this study was challenging enough to induce Type I SD when just visual orientation symbology was presented in the cockpit. The second objective was to test the "goodness" of different audio symbology sets for providing additional orientation information.

Method

Participants

Five males and one female participated in this study. Participants were office workers with no piloting experience. The average age of the participants was 27.5 years.

Apparatus

Evaluation cockpit. A fixed-based single-seat generic fighter cockpit simulator was used for this evaluation (Figure 1). It contained a side-mounted, limited-displacement stick with an F-15 grip, and F-15E throttles. The head-down display formats were portrayed on a single 21" x 16" Matsushita color monitor. A BARCO Retrographics 801 system supported the out-the-window scene, providing a 40° horizontal by 30° vertical field of view.

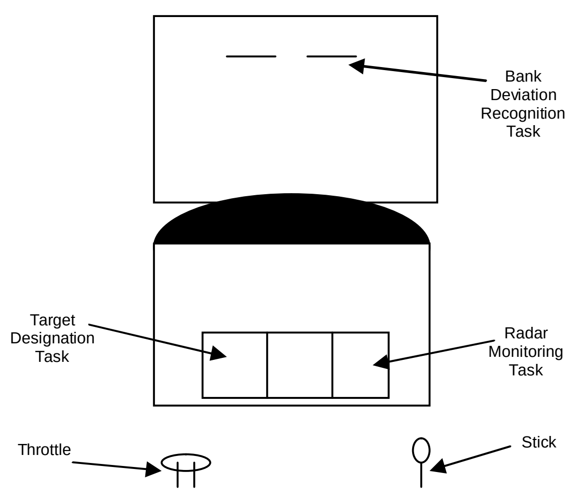

Figure 1. *Evaluation Cockpit*

3-D Localized Audio System. NASA's Sound LABoratory (SLAB) Version 5.3.0 (http://human-factors.arc.nasa.gov/SLAB) (Miller, 2002) generated and presented the 3-D localized audio symbology. SLAB is a software-based real-time virtual acoustic environment rendering system. The software was hosted on a PC and allowed for the specification of position (azimuth and elevation) and volume of the audio input. The third dimension, range, remained fixed for this study. SLAB interfaced with a head tracker to receive head orientation information and modify the location of the sound so the location of it appeared stationary. The audio symbology was presented via Panasonic headsets, which were worn by the participants during the study.

Head Tracker. An Ascension Flock-of Birds 6-D Multi-Receiver/Transmitter Tracking Device was attached to the participant's headset to measure head position coordinates and orientation angles. This information was sent to the 3-D audio system to ensure that the 3-D audio tones were properly correlated with the participant's head position.

Cockpit Tasks

Participants were required to perform three tasks simultaneously. Two of the tasks were conducted on the head-down display; the third was conducted on the head-up display.

Target Designation Task. This task was employed on the left portion of the head-down display (Figure 1). The goal of this task was to find the target symbol (diamond) as fast as possible. Also present with the target symbol were 252 distracter symbols; 84 boxes, 84 upright triangles, and 84 upside-down triangles. Figure 2 shows a sample screen of the target designation task. To select a target symbol, the participant slewed a button on the throttle until the cursor on the screen overlaid the target symbol. Then the participant pressed a button on the control stick to designate the target. As soon as the participant designated the correct target, a new screen appeared. Participants designated as many targets as they could before the trial was completed. Trial length was dependant on the bank deviation task.

Radar Monitoring Task. This task was also employed on the head-down display to the right of the target designation task (Figure 1). The goal of the radar monitoring task was to keep the strength of the radar at an optimal level. This was achieved by keeping a status bar as close to the center mark (0) as possible. Figure 3 shows the radar monitoring task display.

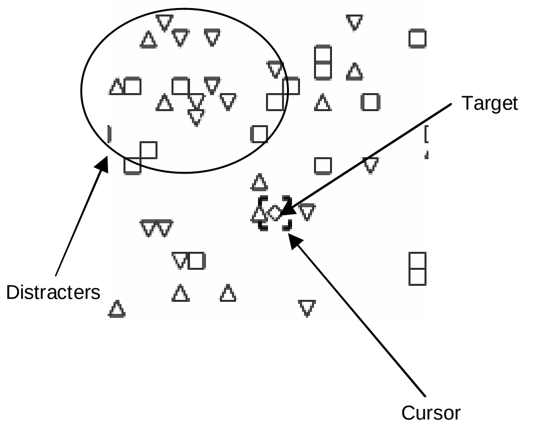

Figure 2. *Target Designation Task*

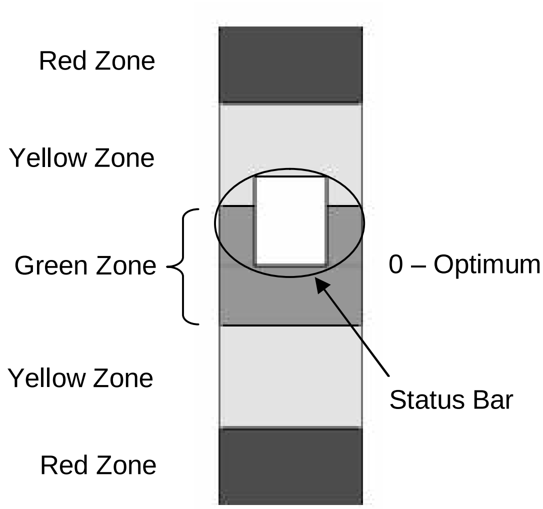

Figure 3. *Radar Monitoring Task*

The status bar was driven by a function of four sine waves. The participant had to press a switch on the control stick in the down position to get the status bar to move down, and press the same switch in the up position to get the bar to move up. Each switch hit would move the bar a discrete amount, and then the status bar would resume moving according to the function of sine waves.

Bank Deviation Recognition Task. This task was employed on the head-up display, which contained a blue background and a green line (Figure 1). Although the participants were not actually flying an aircraft, the line represented aircraft bank. The purpose of the task was to recognize and correct any bank deviation that occurred. Once a bank deviation was recognized, the participant had to move the control stick in the direction opposite of the bank angle to correct it. For example, if the bank indicator rolled to the left, the participant had to move the control stick to the right to level out the bank deviation. The bank indicator moved at a rate of 10º/s to a maximum of 30º bank, moving to and from wings level. If the participant corrected the bank deviation before the bank indicator reached the full 30º of bank, the bank indicator immediately moved back to 0º bank. The bank angle deviations were presented to the participants at random times. There was a total of 25 right bank deviations and a total of 25 left bank deviations per task. The direction of the bank deviations were presented randomly. The time between bank deviations was random and varied between 0 and 6 seconds.

Audio Symbology

To determine the effects of the addition of audio symbology for maintaining orientation awareness, three different conditions were tested during this study. The first condition was a visual only task in which participants could observe bank deviations only by looking at the visual head-up display. The second condition was a visual plus discrete audio orientation symbology task. In this condition, in addition to the visual head-up display, a discrete audio pattern was activated when the bank indicator deviated from 0º in either direction. Once the audio pattern became active, a 100 ms white noise sound source would pulse at 0.5 Hz directly in front of the participant. The audio display did not stop pulsing until the bank indicator returned to 0º bank. The third condition was a visual plus continuous audio orientation symbology task. In this condition, in addition to the visual head-up display, a continuous audio pattern was active at all times. When bank was 0º, the sound source (100 ms white noise) was located directly in front of the participant. When the bank deviated to the left, the sound source moved to the left at a fixed rate of 30º/s with a maximum displacement of 90º to the left, and vice versa for the right. The fixed rate at which the sound source moved was three times as fast as the bank indicator movement.

Independent and Dependent Measures

There was one treatment variable, Audio Orientation Symbology, with three levels measuring the effect of the addition of audio symbology on the bank deviation task. The three levels were visual symbology only, visual symbology plus discrete audio symbology, and visual symbology plus continuous audio symbology.

Dependant measures were collected for all three cockpit tasks. The dependent measures collected for the target designation task were number of correct targets designated and average search time for a target. For the radar monitoring task, root mean square (RMS) errors from the optimum position was the dependent measure. These measures tested the first objective, which was how much effort the participants were giving to the head-down tasks, and in turn, getting mentally loaded. For the bank deviation recognition task, the dependent measure was average time to react to bank deviations. This measure tested the second objective, which was the effect of adding the audio symbology to the visual orientation symbology for recognizing bank deviations.

It was hypothesized that the audio symbology would enhance performance on the bank deviation recognition task and that the continuous symbology would be the more helpful of the two audio symbology sets. It was also hypothesized that by enhancing performance on the bank deviation task with the addition of audio, performance on the other two tasks would increase due to the lessening of the visual load that would occur when the bank deviation task was augmented by the audio symbology.

Experimental Design

The study had a completely within-subjects design using three levels of one treatment variable – Audio Orientation Symbology. In an effort to control practice effects, complete counterbalancing of the three levels was used.

Procedure

Subjects were first given a standardized briefing on safety and test procedures. Next, the three tasks were explained and training ensued. First, training on the target designation task was conducted. This was broken down into three levels of difficulty. The easiest level consisted of finding the target symbol among 252 box distracter symbols. The next level of difficulty included the target symbol with 126 box distracter symbols and 126 upright triangle (with the point at the top) distracter symbols. The final level of difficulty, and the one used for data collection, included the target symbol, 84 boxes, 84 upright triangles and 84 upside-down triangles (balancing on their point). The participants were given two practice trials at each level of difficultly. Then practice proceeded with the target designation task and the radar monitoring task simultaneously. Finally, training on all three tasks occurred in which participants were given 15 left and 15 right bank deviations each. Participants were instructed to give equal priority to all three tasks. The data collection consisted of three trials that were the same as the practice trials save one detail – the collection trials contained 25 left and 25 right bank deviations.

Results

Determining effects of the Audio Orientation Symbology condition on participant's ability to recognize and correct bank deviations, while at the same time performing a target designation task and a radar monitoring task required a sophisticated statistical procedure called *repeated measures multivariate analysis of variance*. This procedure permits joint testing of multiple dependent variables.

Proper use of the multivariate procedure necessitated correlating the four dependent measures beforehand and creating models based on these correlations. Table 1 shows the correlation matrix.

Table 1. *Correlation Matrix*

	Reaction Time (Bank Task)	Number Targets (Target Designtn Task)	Search Time (Target Designtn Task)	RMS Errors (Radar Task)
Reaction Time	1	0.048	0.356**	0.316*
Number Targets		1	-0.767**	-0.35**
Search Time			1	0.527**
RMS Errors				1

* $p<0.05$
**$p<0.01$

The pattern of correlations required testing two models –Model 1: Reaction Time, Search Time and RMS Errors; Model 2: Number of Targets designated, Search Time and RMS Errors.

For both models, given an N of only 6 participants, the lack of residual (or error) degrees of freedom precluded the robust (to violation of statistical assumptions) omnibus multivariate tests. Fortunately each of the dependent measures in the two models did not violate sphericity for the audio condition, thus enabling "averaged F" tests of the models. In Model 1, there was a significant effect for the Audio Orientation Symbology condition ($F(6,18)=3.071$, p=.030). The strength of the effect (based on Pillai's Trace) was moderate with an eta^2 (partial) of 0.506. Also in Model 2, there was a significant effect for the Audio Orientation Symbology condition ($F(6,18)=2.988$, $p=.033$). The strength of the effect was again moderate and based on Pillai's Trace with an eta^2 (partial) of 0.499. Roy's Largest Root showed stronger effects, an eta^2 (partial) of 0.773 for Model 1 and an eta^2 (partial) of 0.788 for Model 2.

The significant averaged F tests allowed separate tests of each dependent measure in the two models. These univariate tests revealed only Reaction Time as significant for Audio Orientation Symbology condition ($F(2,10)=15.933$, $p=.001$), with a strong effect, eta^2 (partial) of .761. Figure 4 shows the mean reaction time for each audio condition.

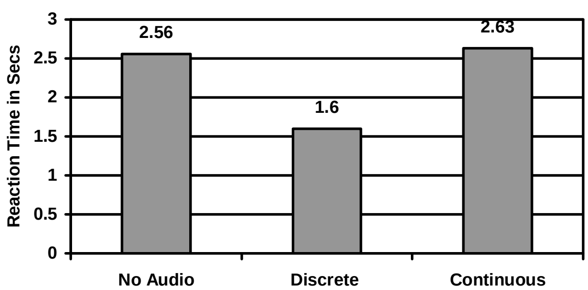

Figure 4. *Raw Means for Audio Orientation Symbology Conditions*

Two further tests revealed which differences among the audio condition levels were strongest: a test of within-subjects contrasts, and Bonferroni paired comparisons. The three levels of the audio symbology condition made two contrasts available. The first compared the discrete mode to continuous, while the second compared the no audio condition to the average of the other two audio conditions. Both contrasts reached significance ($F(1,5)=20.237$, $p=.006$; eta^2 (partial) of 0.802 and $F(1,5)=8.678$, $p=.032$; eta^2 (partial) of 0.634, respectively). The significance found for the second contrast was due to the difference between the discrete mode and no audio as the Bonferroni comparisons attest. The discrete mode was significantly ($p<.05$) on average 1.028 seconds faster (with a standard error of 0.228 seconds, $p=.019$) in Reaction Time than the continuous mode. It was also on average significantly faster ($p<.01$) than the no audio mode, 0.963 seconds (with a standard error of 0.180 seconds, $p=.009$). There was, however, no significant difference ($p>.05$) in Reaction Time between the continuous and the no audio modes (a mean difference of 0.065, standard error of 0.200, $p=1$). Note that mean differences among the Audio Orientation Symbology conditions are slightly at variance with those shown in Figure 4; the Bonferroni procedure bases its comparisons on the estimated marginal means from the models.

Discussion

Results showed that the discrete audio orientation symbology significantly helped participants notice bank deviations more quickly than with the continuous audio orientation symbology or with no audio symbology at all. This is an interesting finding given that the continuous audio symbology provided more information to the participants in terms of the direction of the bank deviation. Recall that the discrete audio symbology sounded in the same manner whenever deviations from 0º bank occurred. It basically provided an audio alarm of bank deviations. The continuous audio symbology sounded when deviations occurred and were presented in the direction of the bank deviations.

Informal questioning of the participants revealed that reaction time on the continuous audio may have been slower because they were initially unable to tell which direction the tone was moving. In other words, they had to wait until they could accurately localize the tone before they could respond, which delayed their reaction time. The disadvantage to this strategy is that it took them longer to respond to the bank deviations. However, the advantage to this strategy is that, once they could determine the direction of the continuous audio, they would respond without taking their visual attention away from the head-down tasks. Therefore, if an adjustment to the continuous audio symbology to allow for quicker initial position detection is possible, this may transition the orientation awareness task to a purely audio task verses yet another visual task.

Since participants were delaying their reaction time to the bank deviation task in the continuous audio condition so they could keep their visual attention focused on the head-down tasks, one would expect to see a performance enhancement in terms of the dependent measures for the other two tasks during the continuous audio symbology condition. This, however, was not the case. Overall results suggest that neither of the audio symbology enhancements had an impact on a participant's head-down work demands per se as shown by the non-significant effects for the audio conditions in terms of the target designation task dependent measures (search time and number of targets designated) and the radar monitoring task dependent measure (RMS errors).

This may be attributed to the fact that, although participants were not using their *visual resources* to perform the bank deviation task while using the continuous audio symbology, they were still required to *cognitively* attend to the task, which competed with head-down task resources.

This argument of cognitive attentional requirements for the bank deviation task versus the head-down tasks holds true for the discrete audio symbology as well. Although results showed a significant decrease in reaction time for the bank deviation task when discrete audio orientation symbology was present, participants were required to go head-up to determine the direction of bank, make the appropriate control stick input, and return to the head-down tasks. Therefore, even though participants performed the bank deviation task faster, it took cognitive resources away from the head-down tasks, and performance enhancements to the head-down task were not found.

It seems certain that the head-down tasks are challenging for the participants to accomplish, and a ceiling effect may be occurring. In other words, regardless of the type of audio symbology used in the bank indication task, the head-down tasks alone are difficult enough to keep the participants busy. Freeing up a small amount of resources as in the discrete and continuous audio symbology conditions, was not enough to show a significant performance enhancement on the head-down tasks. The advantage of using the audio to help with the bank deviation task is evident in the bank deviation task, but not strong enough (yet) to carry over benefits in performing the other head-down tasks. Adjustments to the audio orientation symbology may show these benefits in future studies.

Interestingly, participant performance during the no audio condition of the bank deviation task was just as good as with the continuous audio symbology. This may be attributed to the fact that participants were told to give equal priority to all three tasks. When there was no audio augmentation, participants relied more heavily on a good visual cross-check pattern to detect bank deviations. In any case, it appears that the tasks chosen for this study were challenging enough to provide a good protocol for testing countermeasures for Type I SD in future studies.

Conclusions

This study was successful in that it adequately tested the study objectives. Although the hypotheses were not proven, lessons learned from this study will be leveraged in future studies which will continue to look at ways of reducing Type I SD and augmenting audio orientation symbology to help combat this problem.

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